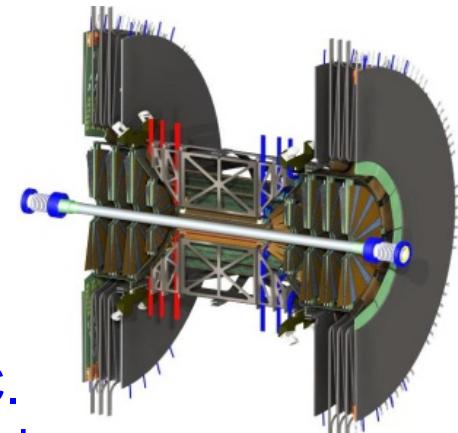


Nucleon Spin and Structure at LANL

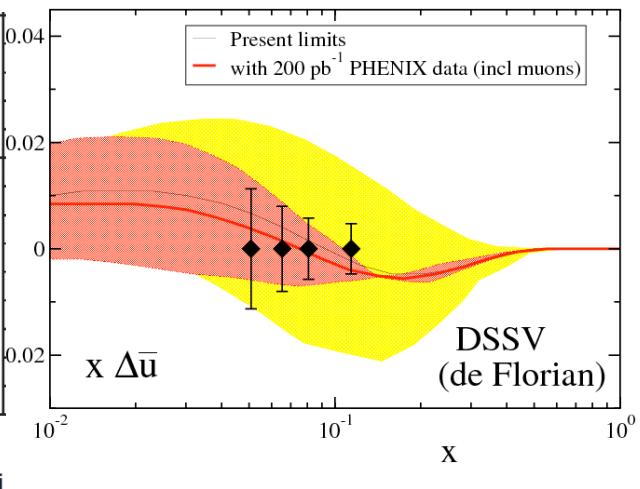
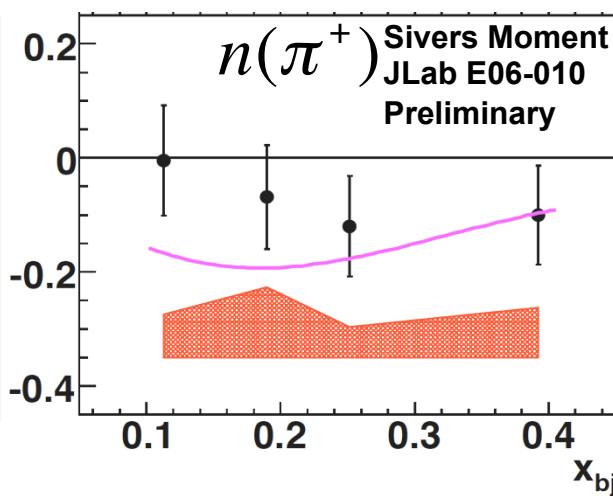
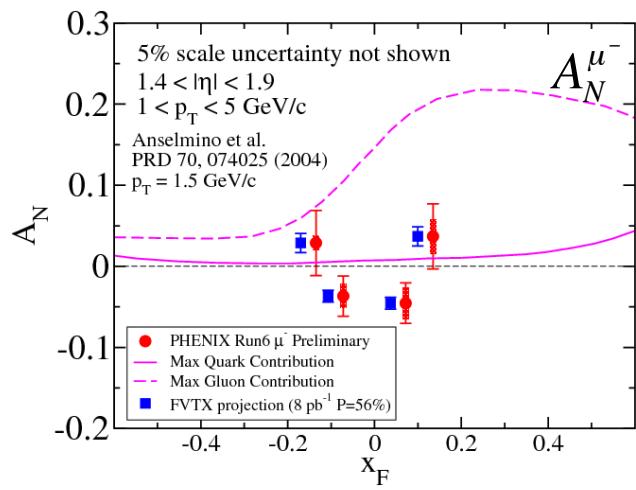
Xiaodong Jiang

DOE-KB01 fund: 1.75 FTE+1.0 PD

LANL fund: Aidala (Reines Fellow), Puckett (Director's Fellow).



- Gluon spin with longitudinal asymmetries at RHIC.
- Parton angular motion - transverse spin asymmetries.
Spin at RHIC : p+p. Spin at JLab: deep inelastic scattering.
- Enabling the future for spin:
 - Forward Vertex Detector upgrade + PHENIX muon arms
 - Increased RHIC luminosity and polarization.



Gluon spin contribution – longitudinal spin asymmetries

$$\frac{1}{2} = \frac{1}{2} \Delta \Sigma_q + \Delta G + L_z$$

quark + gluon + orbital

$\Delta \Sigma_q \sim 0.3$, where's the rest ?

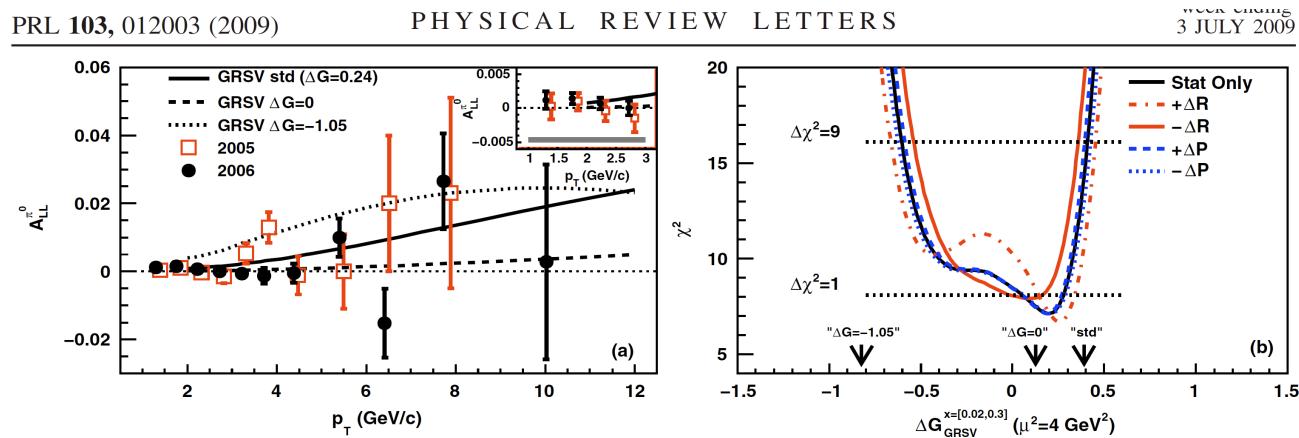
– Gluon $\Delta G = \int_0^1 dx \cdot \Delta g(x)$?

– Orbital angular momentum L_z ?

Leads to the phenomena of single-spin asymmetry (**SSA**).

- $A_{LL}^{\pi^0}$ (PHENIX) and A_{LL}^{jet} (STAR) : the strongest constraints on ΔG

PHENIX - 2009 $A_{LL}^{\pi^0}$: $\Delta G_{GRSV}^{0.02 < x < 0.3} = 0.2 \pm 0.1(stat) \pm 0.1(syst)$



LANL Contributions: analysis of 2006 proton beam polarization

M. Liu, C. Camacho, H. Liu (proton-Carbon polarimeter)

+BNL +Stony Brook (H-jet) Dec. 2007.

Provided fill-by-fill beam polarization for both **STAR** and **PHENIX**.

1st time spin spatial profile corrections made and cross calibration with H-jet reduced $\Delta P_B/P_B$ systematic from **15% → 5%**.

A major milestone for the whole RHIC spin program.

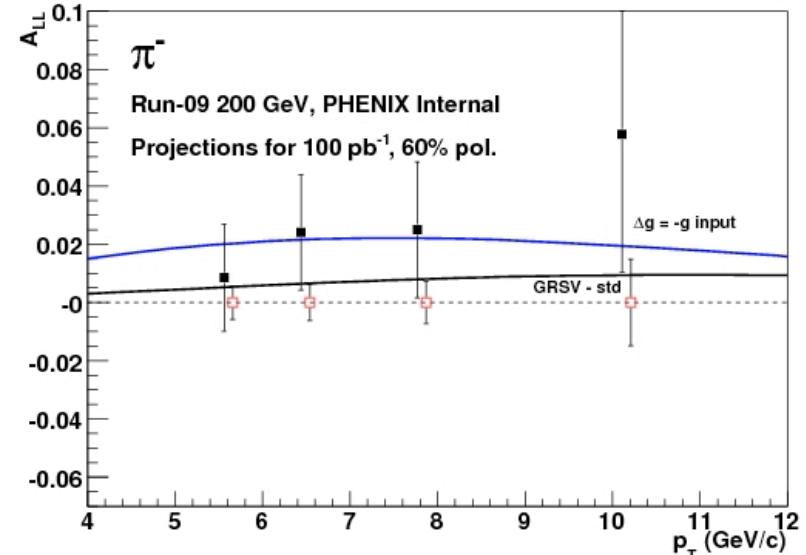
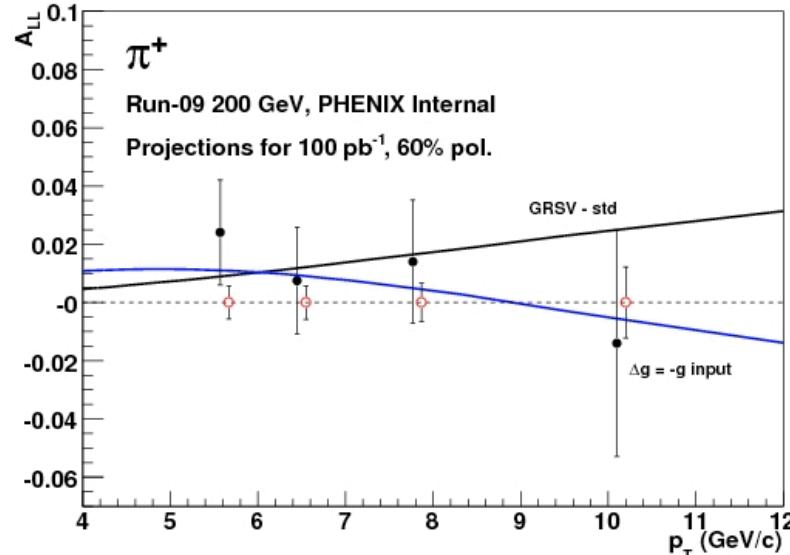
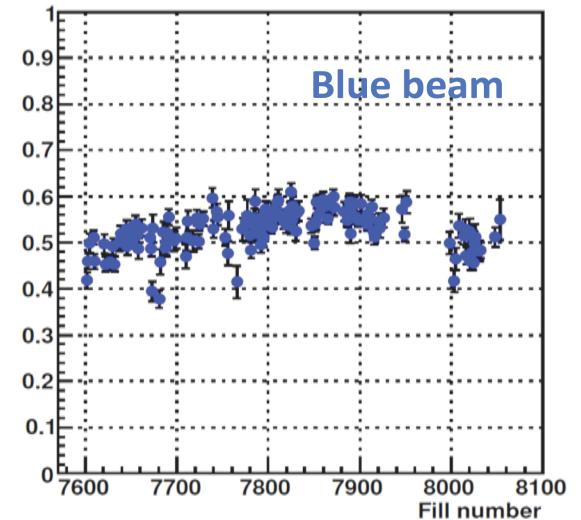
$A_{LL}^{\pi^+}$ and $A_{LL}^{\pi^-}$ are sensitive to the sign of ΔG

(if $\Delta G > 0 \Rightarrow A_{LL}^{\pi^+} > A_{LL}^{\pi^0} > A_{LL}^{\pi^-}$)

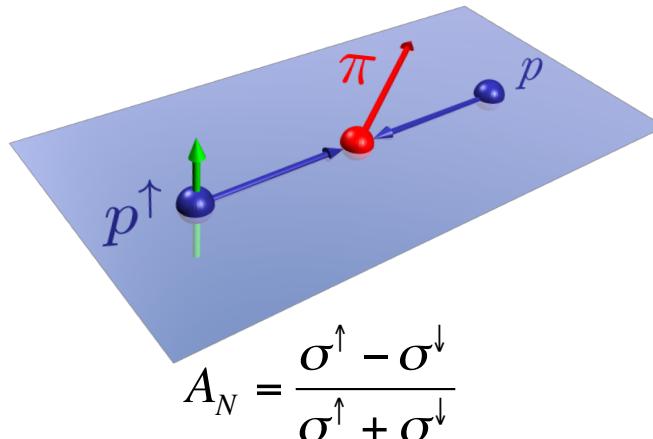
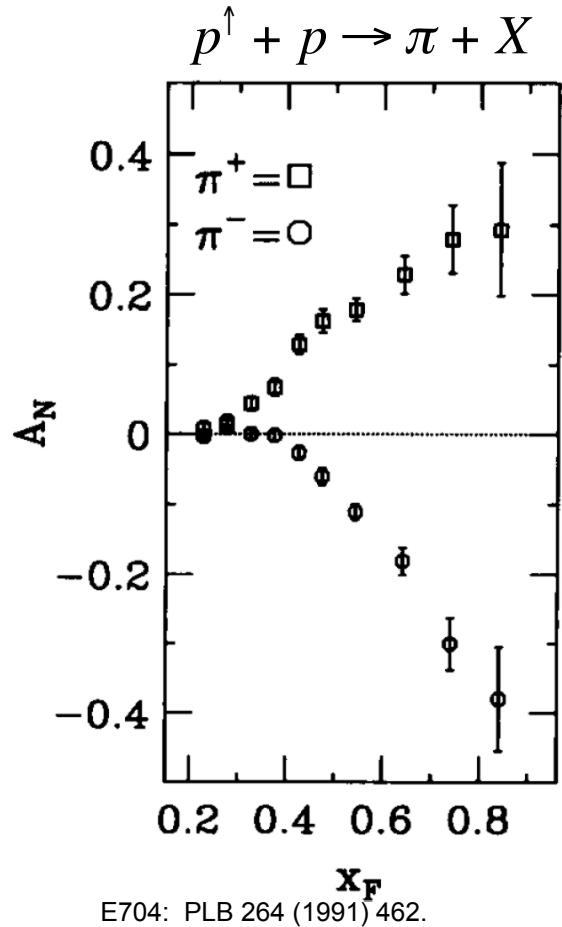
Aidala working with Lee (Stony Brook student).

$$A_{LL} = \frac{1}{\langle P_B P_Y \rangle} \frac{N_{++} - N_{+-}}{N_{++} + N_{+-}}$$

Polarization at peak



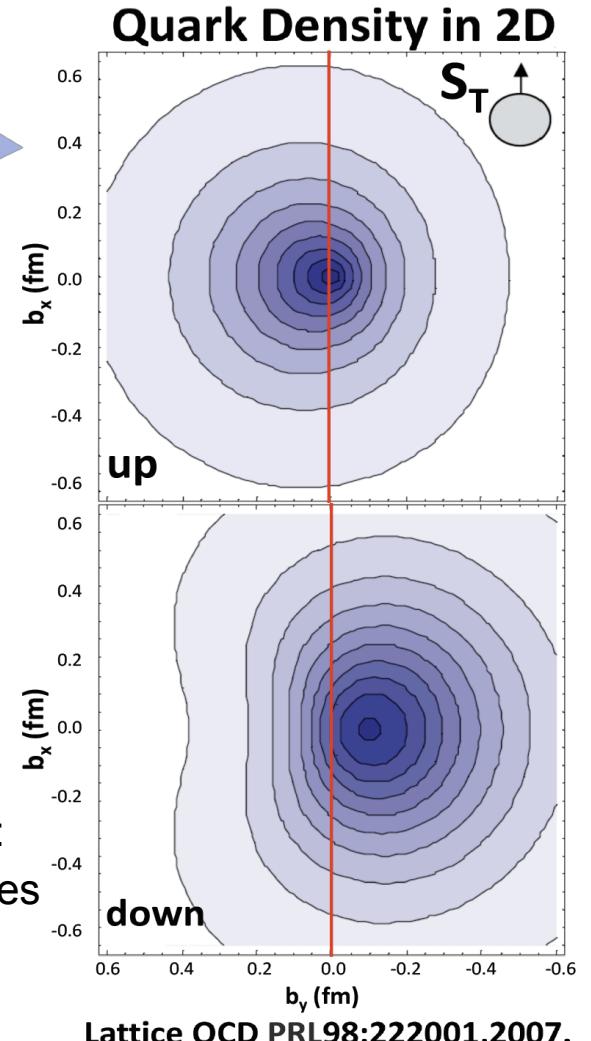
Access parton angular motion through Single-Spin Asymmetry (left-right asymmetry)



π^+ ($u\bar{d}$) favors left

π^- ($d\bar{u}$) favors right

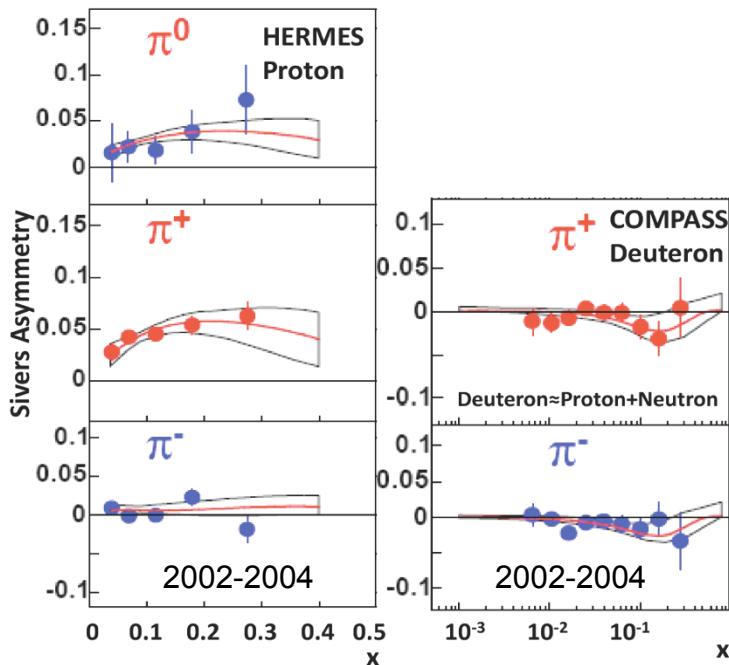
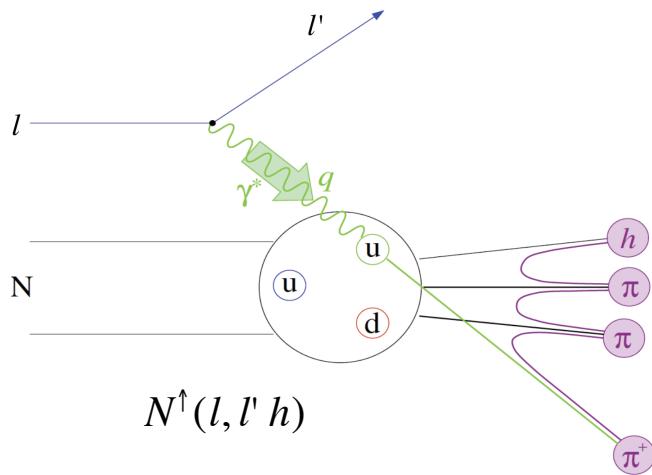
One explanation (Sivers effect):
quark's angular motion generates
a left-right density difference.



up-quarks favor left ($L_u > 0$), down-quarks favor right ($L_d < 0$).

The same Sivers Effect also shows up in lepton scattering

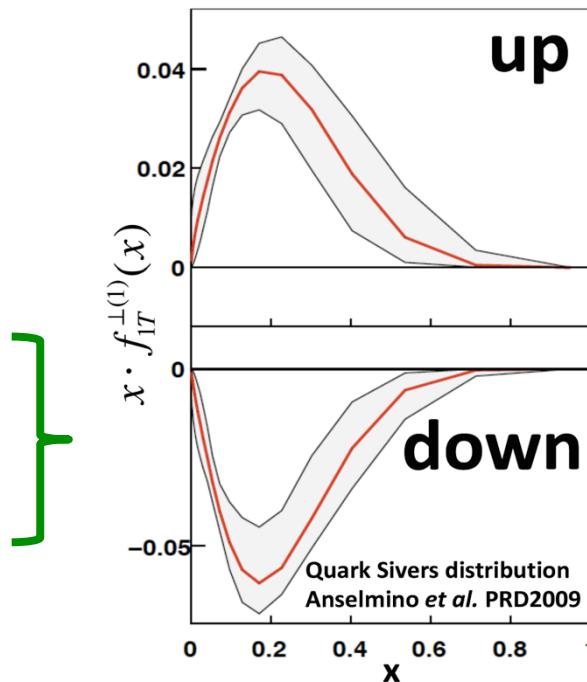
Transverse Target Single-Spin Asymmetry in Semi-Inclusive DIS



Sivers 1990: correlation between nucleon spin and quark transverse momentum.

Forbidden before 2002 quark Sivers distribution $f_{1T}^{\perp q}(x, k_T)$

- Naive T-odd, not allowed for collinear quarks. Transverse Mom. Dep. parton distributions (TMDs).
- Imaginary piece of interference $L_q=0 \times L_q=1$ quark wave functions.
- Gauge invariance of QCD requires Sivers function to flip sign between semi-inclusive DIS and Drell-Yan.

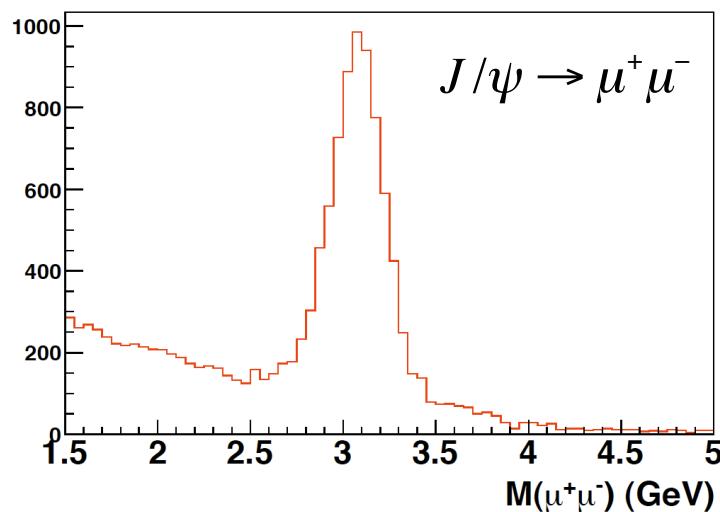
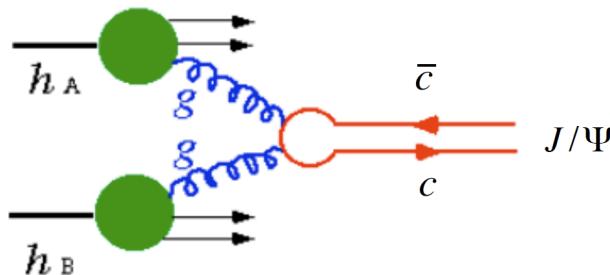


up-quarks favor left ($L_u > 0$),
down-quarks favor right ($L_d < 0$).

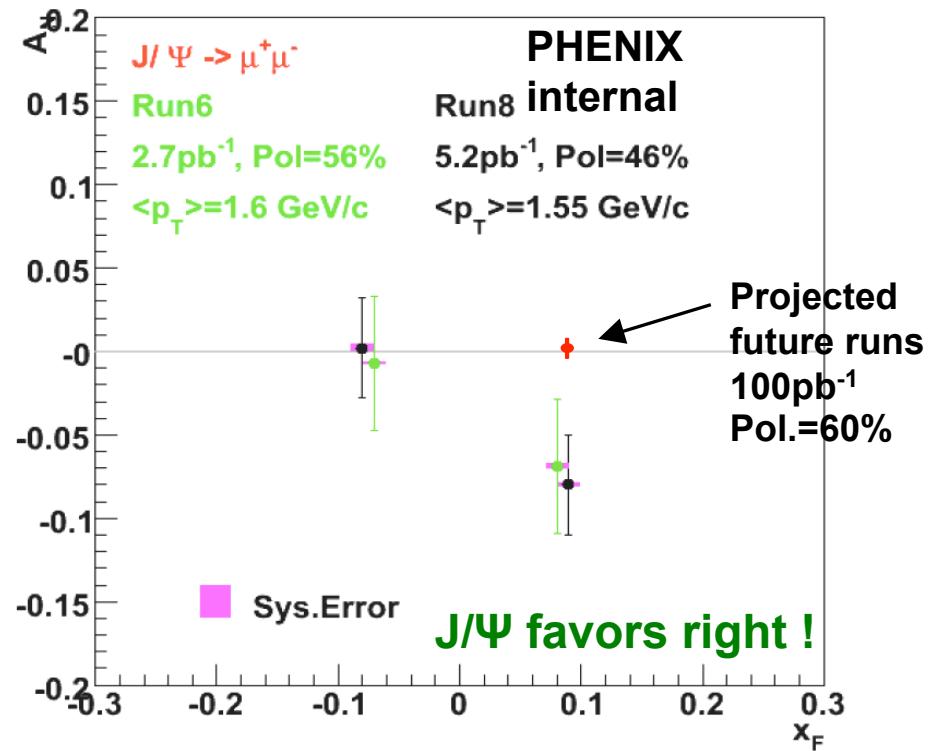
What about the gluons ?

Evidence of gluon angular motion (?)

Single spin asymmetry in: $p^\uparrow + p \rightarrow J/\psi + X$



LANL leads in PHENIX muon-arm analysis:
M. Liu, H. Liu + NMSU+UNM.

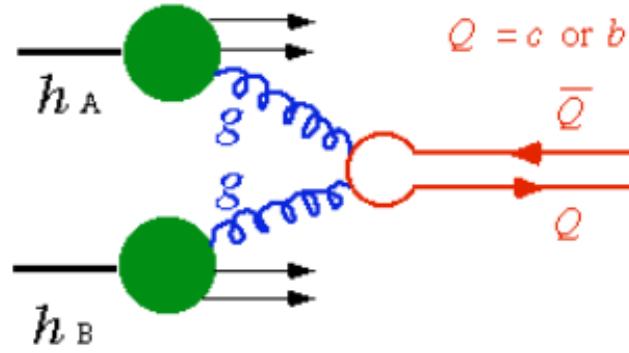


Gluon's angular momentum is opposite to nucleon's spin (?)
(i.e. $L_g < 0$, gluon Sivers has the same sign as d-quark)

Open charm SSA to probe gluon Sivers distribution

D meson Single-Spin Asymmetry:

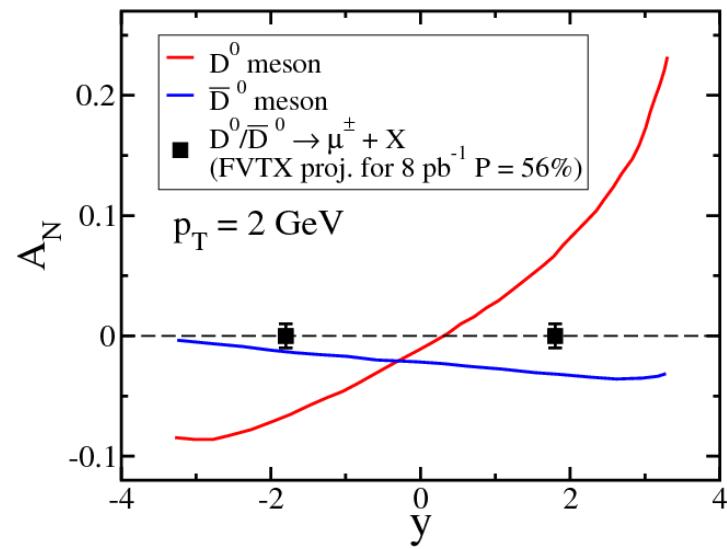
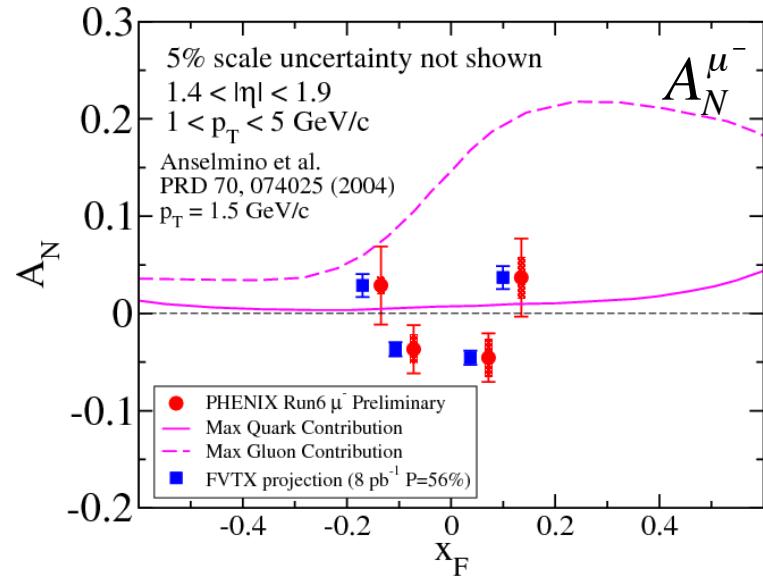
- Production dominated by gluon-gluon fusion
- Sensitive to gluon Sivers distribution
- PHENIX-2006 data ruled out the max. gluon Sivers
- Much improved results expected (Run2006+2008)



LANL leads in muon-arm analysis: M. Liu, H. Liu.

Future improvements with FVTX + Muon

Measure both μ^+ and μ^- single-spin asymmetry.



Kang, Qiu, Yuan, Vogelsang, Phys. Rev. D 78, 114013(2008)

Do strange quarks contribute to angular momentum ?

Single Spin Asymmetry in: $p^\uparrow + p \rightarrow \eta + X$

Preliminary results from STAR suggested larger SSA for η -production than π^0 .

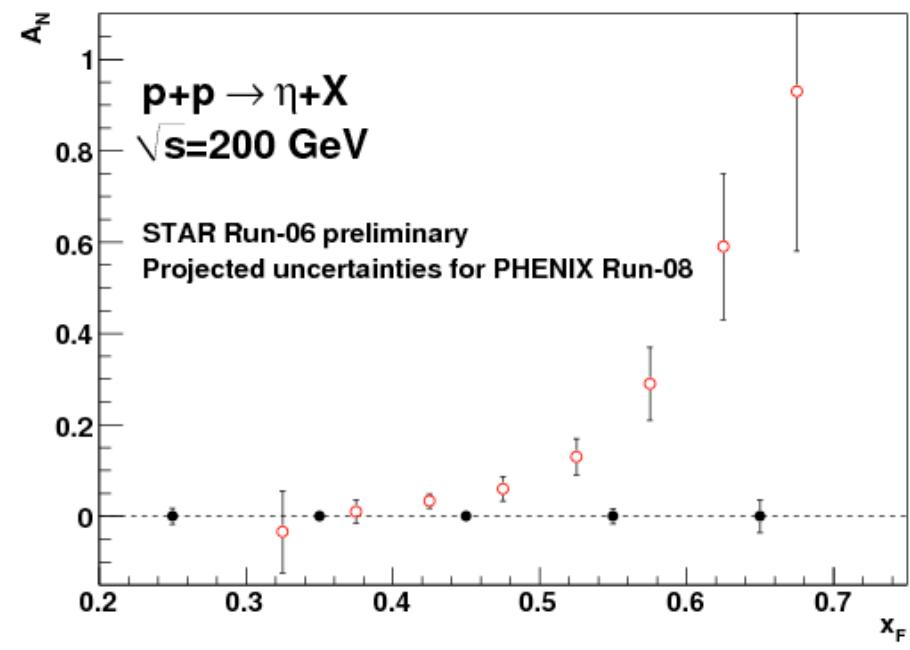
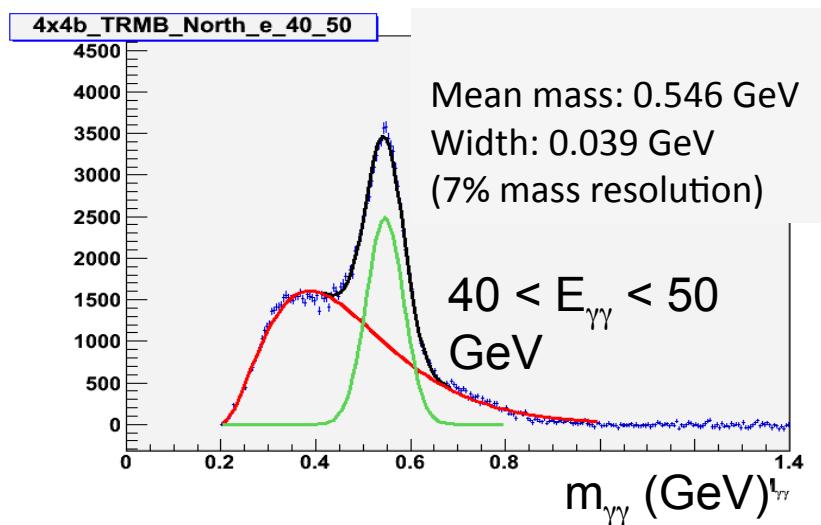
Strange-quarks favor the left side more than up-quarks ?
 (i.e. $L_s > 0$, s-quark Sivers has the same sign as u-quark)

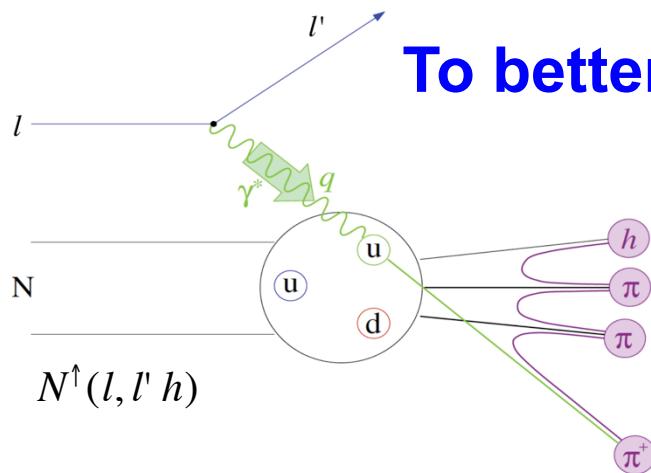
$$\eta \approx \frac{1}{\sqrt{3}}(u\bar{u} + d\bar{d} - s\bar{s})$$

$$\pi^0 = \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$$

Aidala guiding Kleinjan (UC Riverside student).

- PHENIX forward calorimeter (MPC) data.
- Preliminary results in June 2010.

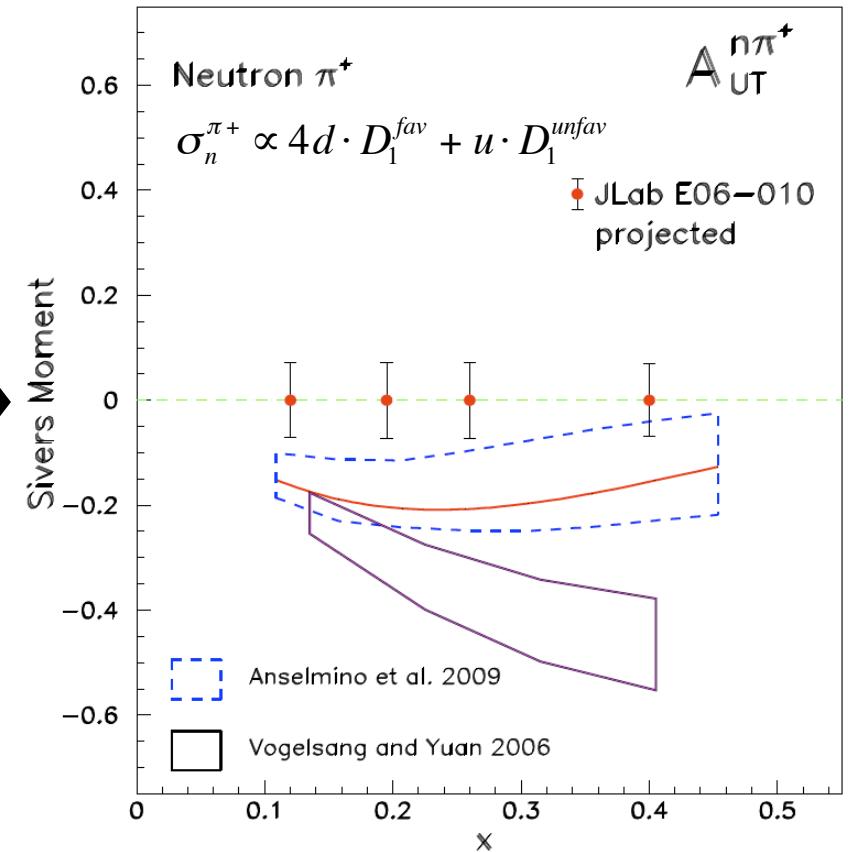
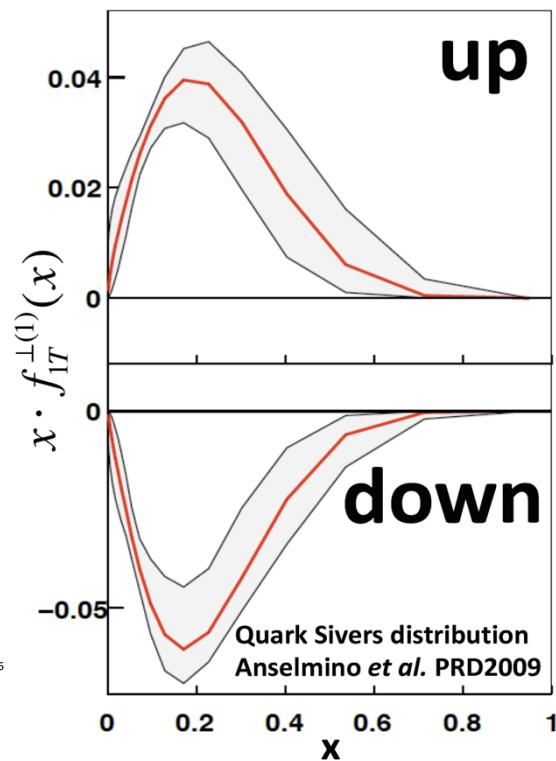
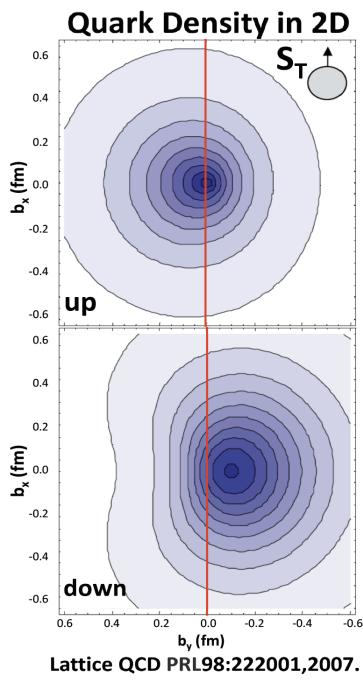




To better constrain quark Sivers distributions ...

Target single spin asymmetry in semi-inclusive DIS

- Proton: HERMES 2002-2004.
COMPASS 2006-2007, 2010-2011.
- Deuteron: COMPASS 2002-2004.
- **Neutron (${}^3\text{He}$): JLab E06-010, Oct. 2008-Feb. 2009.**



Neutron SSA in SIDIS: JLab E06-010

Jiang: co-spokesperson and contact person. **Guo:** run coordinator.

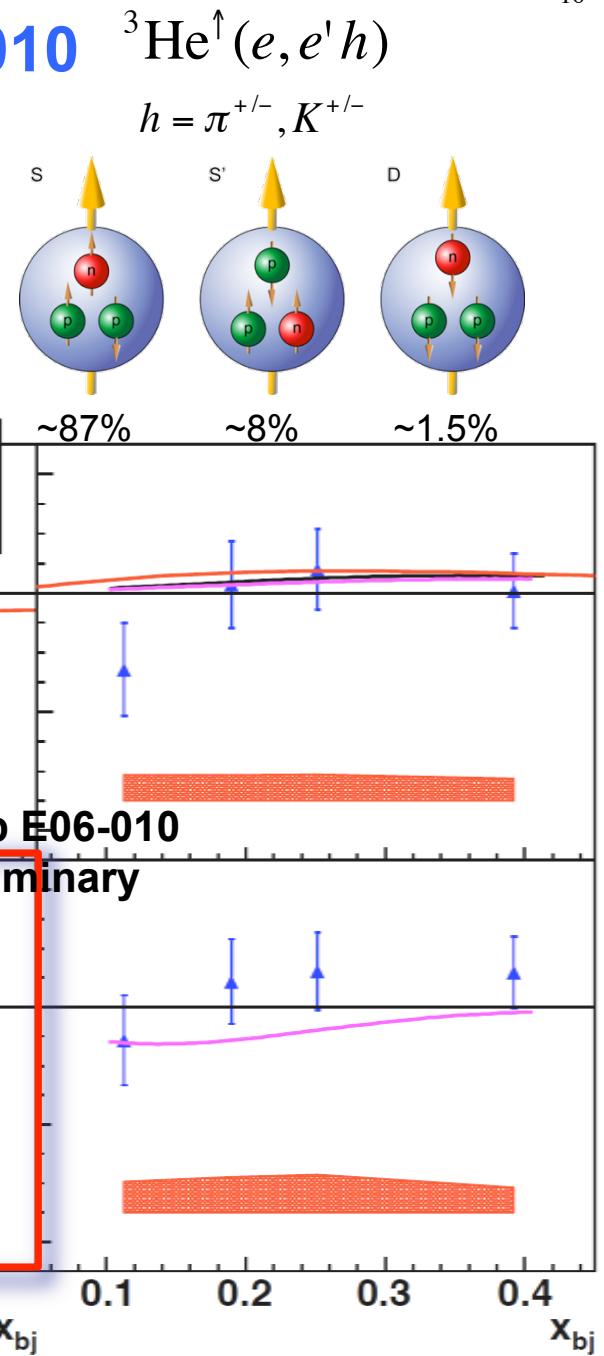
Puckett: leads in data analysis and Monte Carlo simulation.

110 shift workers, 7 Ph.D. thesis.

- Strong constraints on quark Sivers and transversity.

- New JLab-12 GeV experiment approved.** E10-006

(SoLID-Transversity, Jiang co-spokesperson) in conjunction
with E10-007(SoLID-PVDIS).



**Neutron Sivers SSA
are smaller
than expected.**

**d-quark Sivers need
to reduce by ~half.**

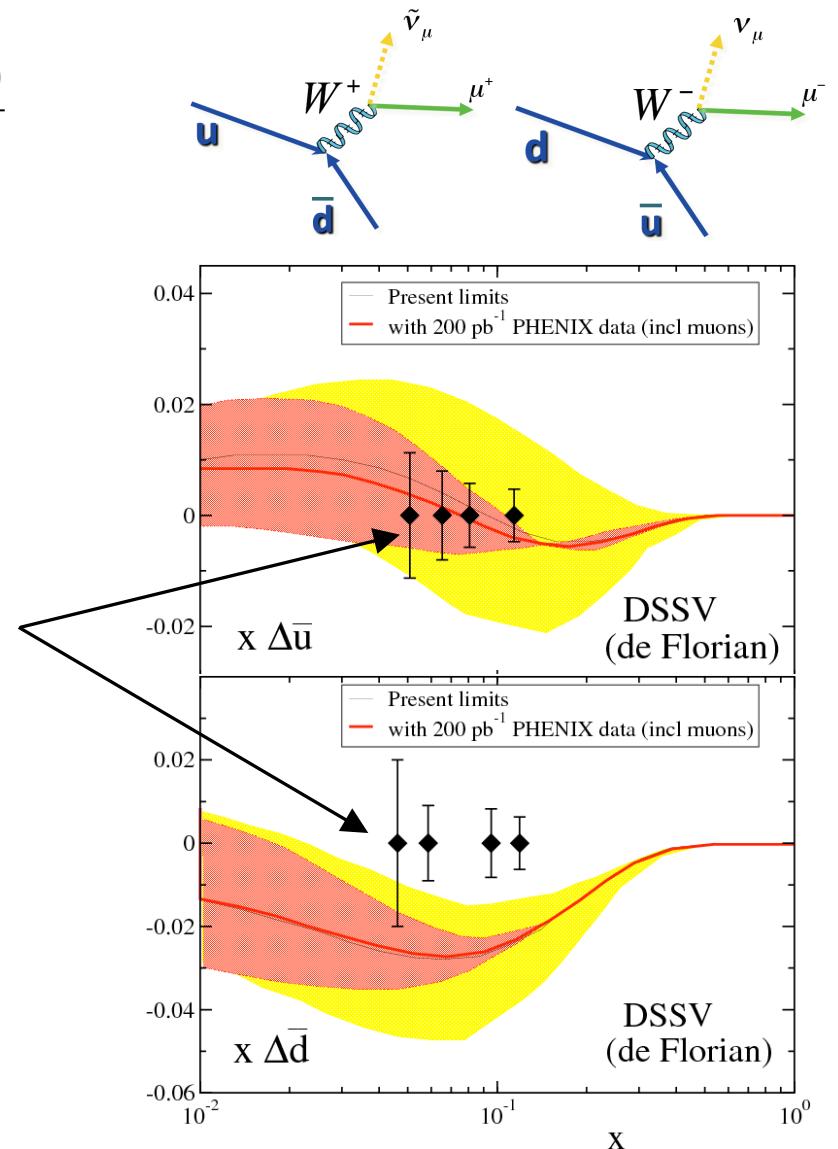
Δq and $\Delta \bar{q}$ through W^\pm decay (DOE Milestone HP8, 2013)

$$A_L^{W+} = \frac{\sigma^{\rightarrow} - \sigma^{\leftarrow}}{\sigma^{\rightarrow} + \sigma^{\leftarrow}} \propto \frac{\Delta \bar{d}(x_1)u(x_2) - \Delta u(x_1)\bar{d}(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}$$

$$A_L^{W+} : \frac{\Delta u}{u} \text{ and } \frac{\Delta \bar{d}}{\bar{d}}. \quad A_L^{W-} : \frac{\Delta d}{d} \text{ and } \frac{\Delta \bar{u}}{\bar{u}}.$$

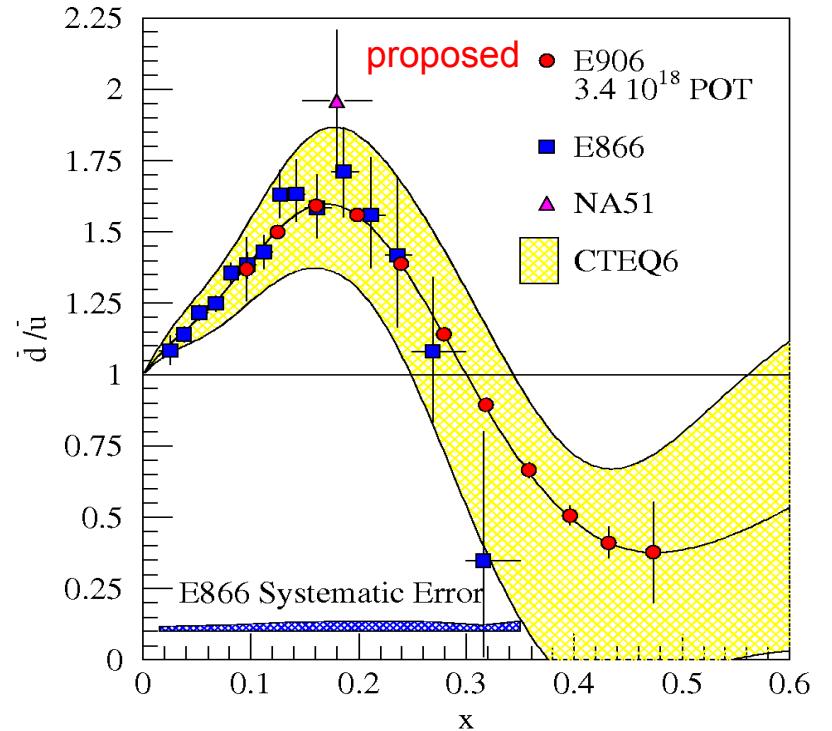
Present Muon tracker spectrometer effective resolution ($\sim 300 \mu\text{m}$) good enough for J/ψ

- need (design) $100\mu\text{m}$ resolution to separate W^+ from W^- at high momentum
- LANL studying detector issues (i.e. calibration, alignment) to reach the design resolution:
 - $\Delta p/p$ & charge separation
 - Cluster fitting to chamber alignment
 - Background rejection with FVTX
 - Muon Trigger R&D, installation and commissioning



FNAL-E906: \bar{d} / \bar{u} in proton

- E866 showed $\bar{d} \neq \bar{u}$ versus x_1
- Behavior at large $x_1 (>0.3)$ not known
- Result of pion cloud around nucleons?
e.g. $p \rightarrow \pi^+ + n$ gives \bar{d} excess
- Connection between \bar{d} / \bar{u} asymmetry and orbital angular momentum of quarks
- E906 at FNAL will reach $x_1 \sim 0.5$ using Drell-Yan with 120 GeV proton beam



$$I_{fas} = \int_0^1 [\bar{d}(x) - \bar{u}(x)] dx = \langle p \uparrow | l_3 | p \uparrow \rangle$$

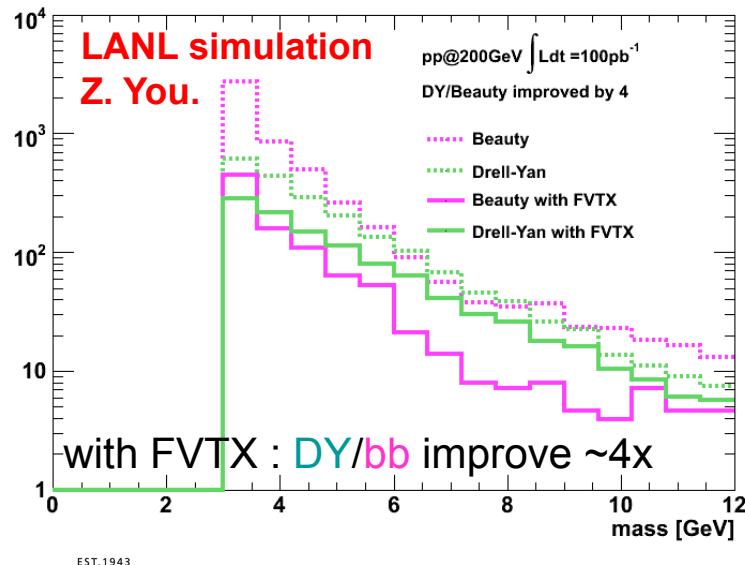
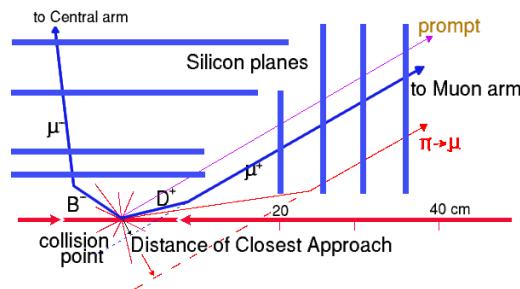
Nucleon's angular momentum = 0.147 ± 0.027

(pion cloud, Garvey arXiv:1001.4547)

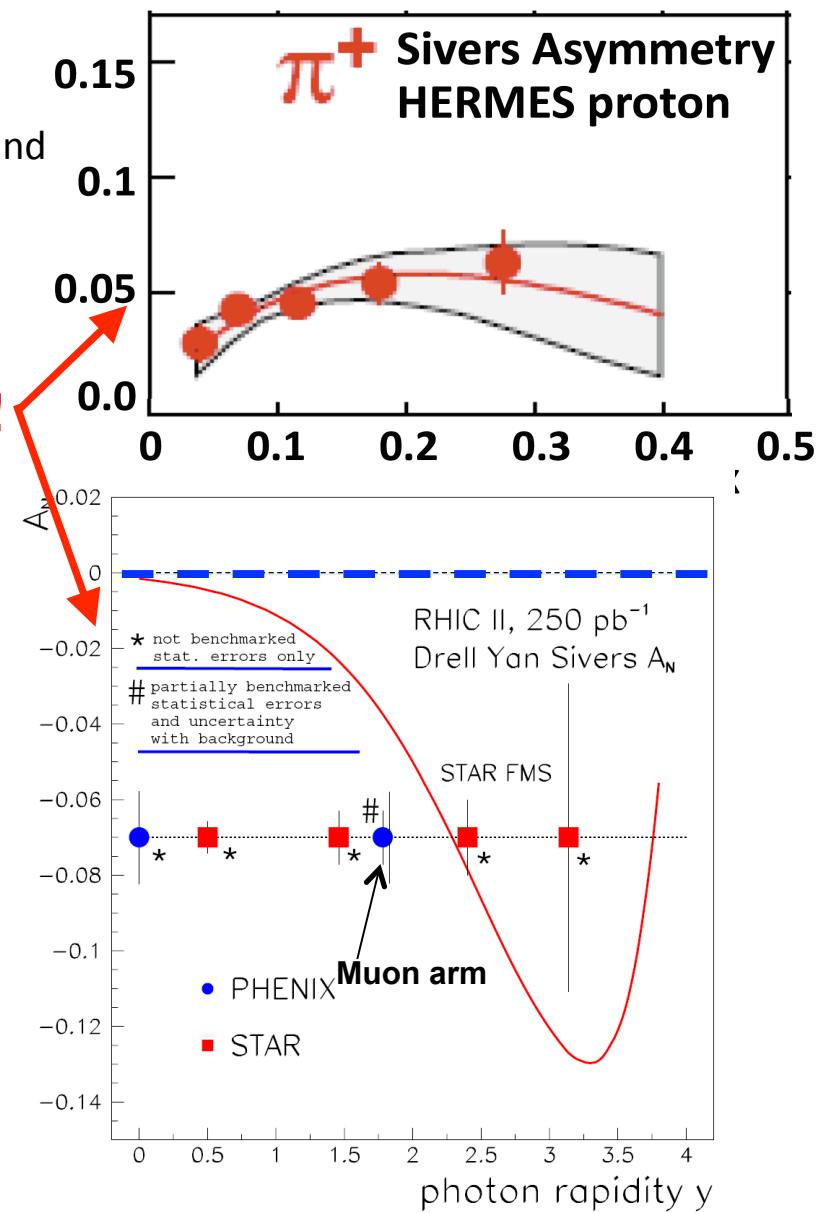
2010 – 2015 Transverse Asymmetry in Drell- Yan ($\text{qq} \rightarrow \mu^+ \mu^-$)

NSAC Milestone: HP13 “Test unique QCD predictions for relations between single-spin phenomena in p-p scattering and those observed in deep-inelastic scattering”.

Gauge invariance in QCD →
Sivers asymmetry flips sign !



Xiaodong Jiang



Summary – Nucleon Spin and Structure at LANL

- Pursuing contributions to nucleon spin from orbital angular momentum
 - Build on our expertise on forward muon single-spin asymmetry.
 - Open heavy flavor and J/ ψ single-spin asymmetry gave the 1st indications.
- JLab E06-010 add strong constraints to quark Sivers and transversity distributions.
- W^\pm measurement a challenging milestone.
 - LANL working to solidify muon tracker charge separation, and to control backgrounds using new FVTX.
- E906 improves knowledge of nucleon sea.
- Working towards 1st Drell-Yan single-spin asymmetry measurement, FVTX rejection of background is key.

